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Astrophysics on the lab bench

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Abstract
In this article some basic laboratory bench experiments are described that are useful for teaching high school students some of the basic principles of stellar astrophysics. For example, in one experiment, students slam a plastic water-filled bottle down onto a bench, ejecting water towards the ceiling illustrating the physics associated with a type II supernova explosion. In another experiment, students roll marbles up and down a double ramp in an attempt to get a marble to enter a tube half way up the slope, which illustrates quantum tunnelling in stellar cores. The experiments are reasonably low cost to either purchase or manufacture.

Introduction
This article describes 10 hands-on bench top experiments that are useful for teaching high school students the basic principles of stellar astrophysics. Over the last several years, a Space Day has been held at QUT in which 50 – 60 year 8 – 10 (13 – 15 years of age) students are given a PowerPoint presentation on stellar astrophysics and then perform 10 basic experiments in the first year physics laboratory. After lunch, students are shown a space DVD before returning to school. The purpose of the Space Day is to try and foster an interest in science in the year 8 – 10 group and increase the number of students electing to study science in senior high school and university (preferably QUT). This is against a background of a decline in the number of Australian high school students studying science (Fullarton and Ainley (2000)) and the International Astronomical Union (IAU 2003) resolution on the value of astronomy education. Others have also used space themes to motivate school students to study science (Verbickas 2002).

Star Works presentation
The *Star Works* presentation gives students a basic introduction to stellar astrophysics and includes spectacular images from the Hubble Space Telescope. Topics discussed include nebulae and stellar formation, nuclear fusion in stellar cores, red giants, planetary nebulae, white dwarfs, supernovae, neutron stars and black holes.

Laboratory Session

Ten experiments are set up at a numbered location around the first year physics laboratory and students are divided into 10 groups and rotate through the 10 experiments.

Table 1. Experiments illustrating aspects of stellar astrophysics.

Exp	**Activity**	**Astrophysical principle**
1	Syringe/temp probe	Stellar formation/hydrostatic equilibrium
2	Boules/trampoline	Collapse of Bok globules etc
3	Electroscope	Electrostatic repulsion in stellar cores
4	Van-der-Graf	Electrostatic repulsion in stellar cores
5	Plasma ball	Hydrogen emission nebula
6	Ramp/marbles	Quantum tunnelling in fusion
7	Plastic water bottle	Core bounce in a type II supernova
8	Rotating chair	Conservation of angular momentum in SN core collapse
9	Funnel/marbles	Accretion and heating of matter close to a black hole
10	Spectroscope	Importance of spectra in astrophysics

The 10 experiments are listed in table 1. Each student is given a sheet to complete for each experiment. In experiment 1, students quickly press in a syringe plunger and record the resulting temperature rise. Students then allow the plunger to naturally go back to the rest position and then pull the plunger out beyond the rest position and record the decrease in temperature. This experiment illustrates that compressed gas heats – as it does when a gas cloud collapses in space giving rise to a protostar. Students also learn that expanded gas cools – as happens, for example, when a stellar core expands. This relation between temperature and volume introduces students to the concept of stellar hydrostatic equilibrium.

In experiment 2, students place metal balls around the edge of a small exercise trampoline. When they let go of the balls simultaneously the balls tend to migrate to the centre of the trampoline, speeding up as they get close to the centre as the canvas is being depressed, imitating the curvature of space-time by mass. The balls are analogous to molecules in a gas cloud being drawn together by gravity in a nebula.

Experiment 3 is a demonstration of electrostatic repulsion using a gold leaf electroscope. Students charge up a comb by combing it through their hair and bring the comb down towards the metal plate at the top of the glass jar of the electroscope. If the humidity is low, the gold leaf will move away from the central bar. This experiment illustrates electrostatic repulsion that occurs between protons and nuclei in stellar cores. The temperature in the core of any star burning hydrogen is too cool for protons to get close enough together (within 10^{-15} m) to fuse. However, quantum tunnelling enables protons and nuclei to get close enough together to fuse, which is the topic of Experiment 6.

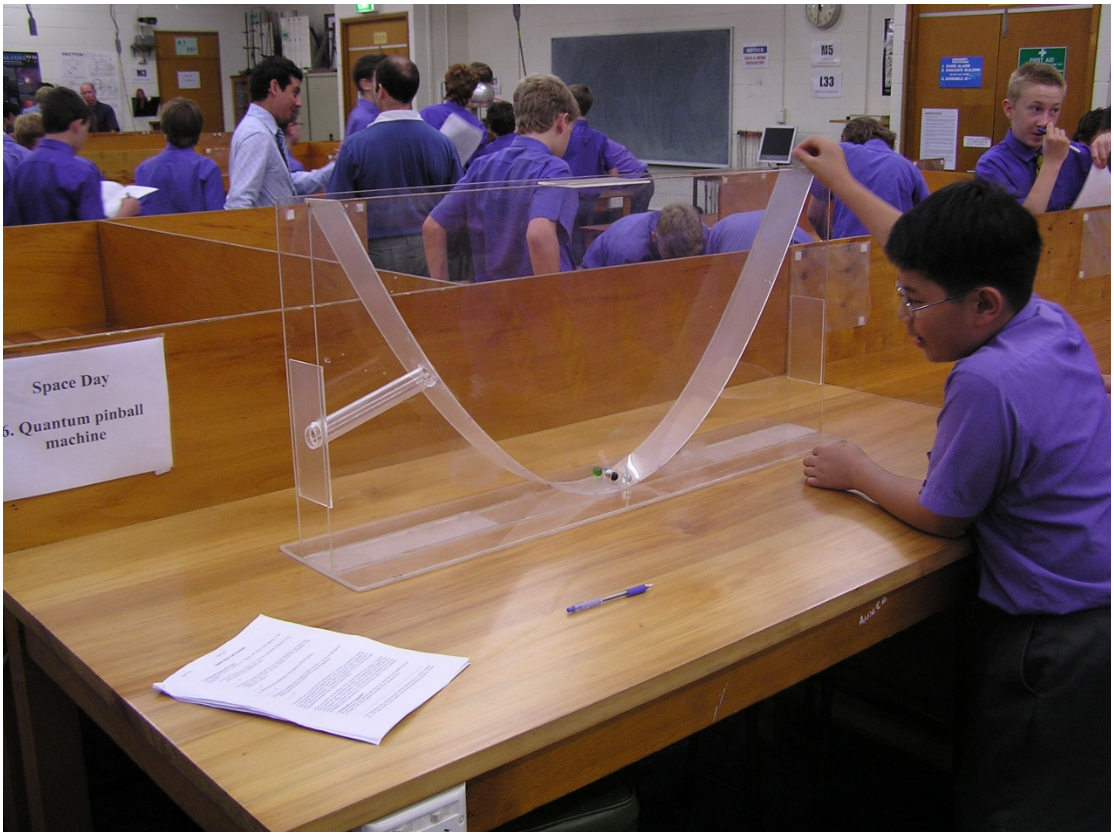

Figure 1. The ‘quantum pin-ball machine’ illustrating quantum tunnelling.

In experiment 6, students roll marbles down one side of a ‘U’ shaped ramp and attempt to get a marble to enter a tube projecting horizontally into the opposite side of the ramp (figure 1). This is quite a challenge – deliberately so as it impresses on the students the fact that quantum tunnelling is a rare event.

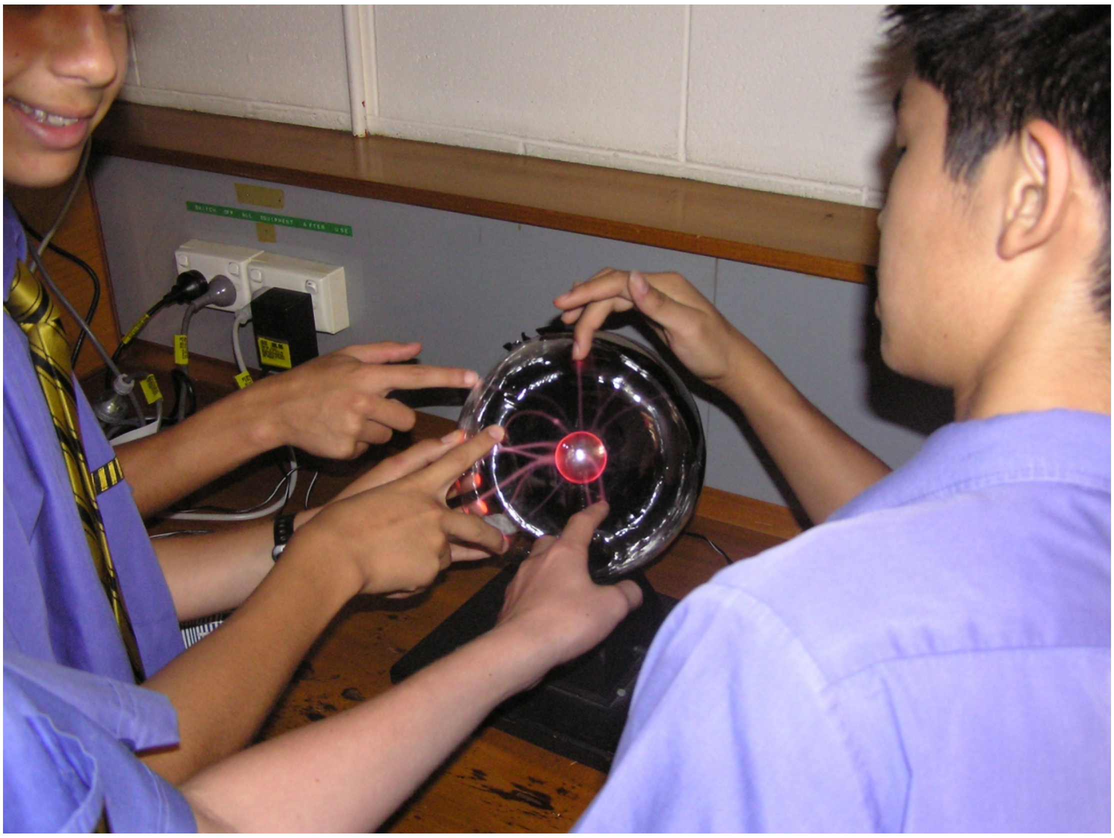

Figure 2. A plasma ball exhibiting the same pink glow seen in hydrogen emission nebular in space.

Figure 3. The Eagle nebula. The hydrogen gas is excited by the light coming from the embedded stars causing the pink glow – the same pink glow seen in a plasma ball. Image courtesy of Johannes Schedler (http://panther-observatory.com/).

In experiment 5, a plasma ball (figure 2) is used to enable students to experience firsthand the pink glow of hydrogen emission nebulae such as the one shown in the telescope image in figure 3 taken by Austrian astronomer Johannes Schedler. The pink glow of a nebular cannot be seen with the naked eye even through a large telescope as the light intensity is too faint. Long time exposures are required to detect colour. So the only way of seeing the same pink colour directly by eye is to see it in the laboratory using something like a plasma ball.

In experiment 7 students are asked to fill a small plastic bottle with water and slam it down onto a laboratory bench, and note how high the water is ejected (figure 4). This illustrates core bounce in a type II supernova explosion and consequent ejection of stellar material (ignoring the assistance of neutrinos). This experiment is called the 'supernova cola experiment', but students are warned not to try this experiment at home in the kitchen using coke.

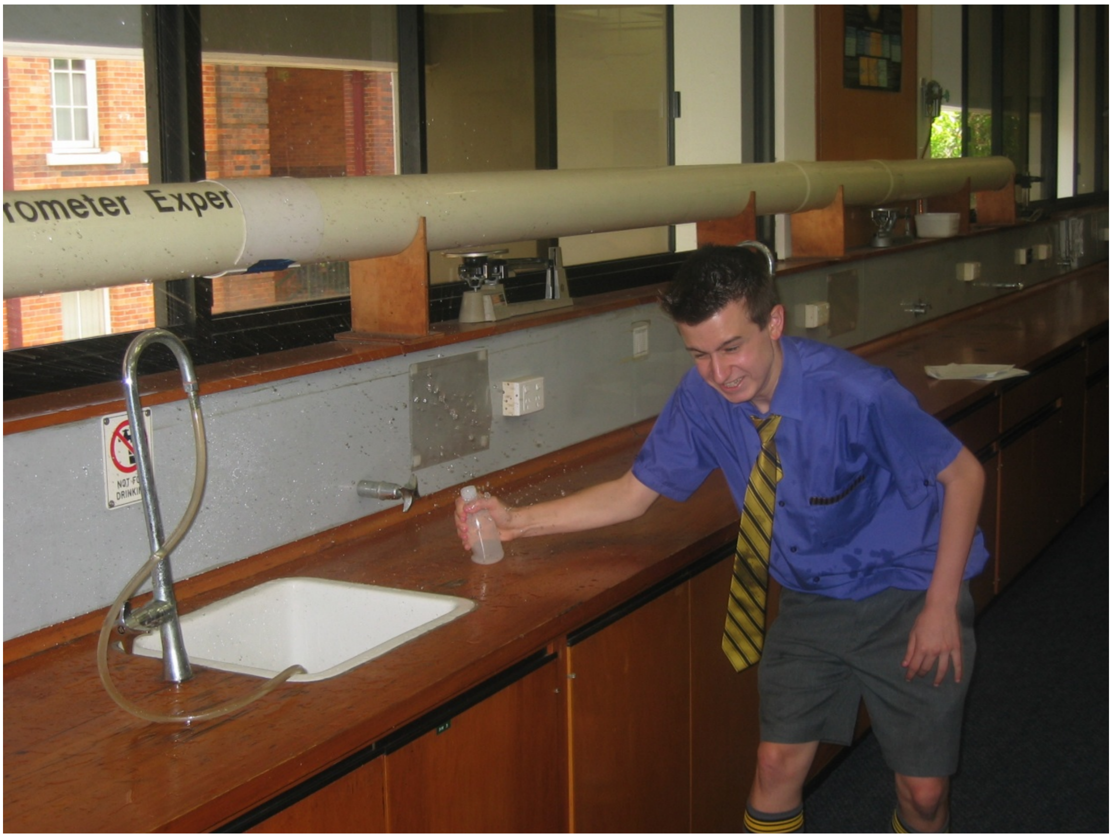

Figure 4. The 'supernova cola' experiment illustrating the physics behind core collapse in a supernova. A plastic bottle filled to the brim with water is banged down onto the bench ejecting water to a height of several meters.

After a large star has exploded it leaves behind a rapidly spinning hot core which in some cases becomes a neutron star. Due to the conservation of angular momentum, the compact core is spinning very much fast than before. For example, the rotation rate of a core may change from one rotation every several days to 30 times s^{-1} only (the current rotation rate of the neutron star at the centre of the Crab nebula). The spin-up of a neutron star can be modelled using a rotating chair. A student sits on the chair and stretches out their arms and legs. Other students in the group grab hold of an arm or leg and spin the student. Whilst spinning, the student draws in their limbs and rotates faster. A purpose built stool is used in the first year lab, but in principle any spinning office chair could be used.

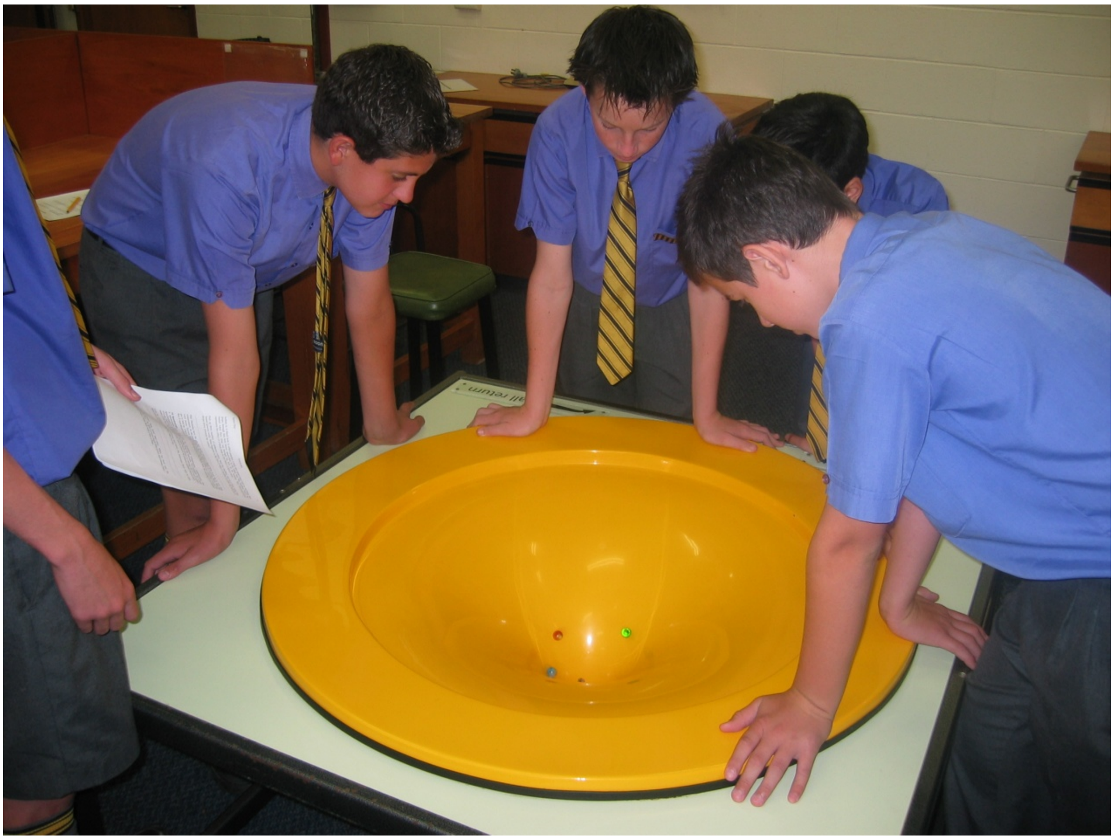

Figure 5. Coloured marbles rotating in the black hole gravity well. As marbles approach the bottom of the gravity well they spin faster, illustrating the differential rotation that occurs when matter is sucked into a black hole.

In some cases, the core of a large star keeps on shrinking and turns into a black hole with an escape velocity greater than the speed of light. In effect a hole in punched into space-time. This can be modelled using a curved funnel as shown in figure 5. Students roll different coloured marbles around the funnel and observe that as marbles get closer to the bottom they speed up and eventually disappear from view down the central (black) hole. The funnel models the accretion disc of a black hole, in which material closer to the centre spins faster than at the edges.

Differential rotation in the accretion disc of a black hole causes friction between the rotating layers which can become so hot that x-rays are emitted that can be detected by space-borne telescopes such as Chandra (http://chandra.harvard.edu/). Radio telescopes have detected steep increases in the velocity of stars and gas clouds at the centre of galaxies presumably to be due to the presence of a black hole. Figure 6 shows an x-ray image taken by NASAs Chandra X-ray telescope of a radio source called Sagittarius A* that is thought to be associated with a super massive black hole at the centre of our galaxy[i].

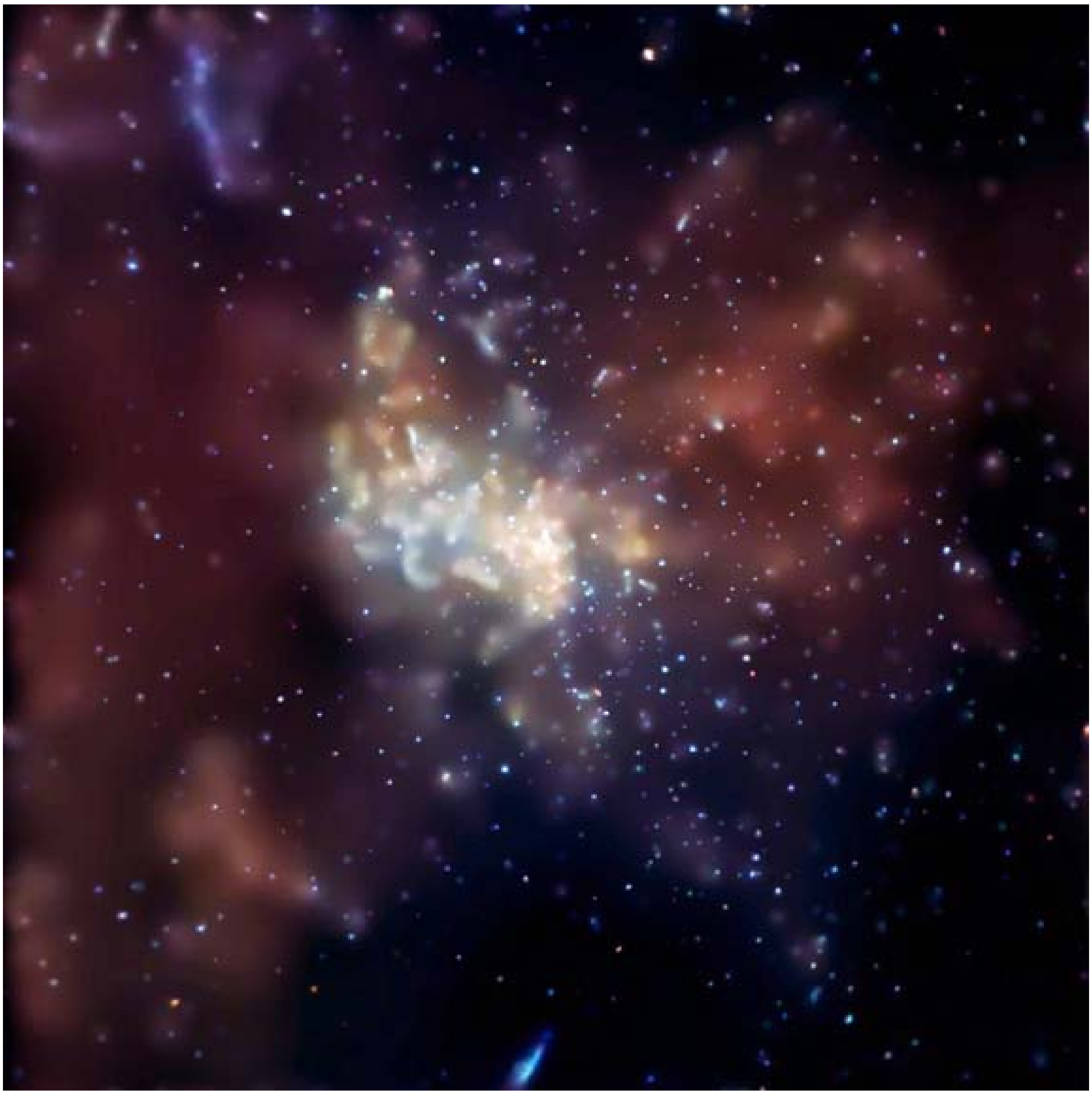

Figure 6. Chandra x-ray image of Sagittarius A* at the centre of our galaxy the Milky Way. Some of the regions in this image have a temperature of 20 million degrees centigrade.

The final experiment (10) gives students an experience of looking at a mercury lamp through a spectroscope. Students are able to observe the orange, blue, green and purple lines that make up the spectrum. Spectroscopy is an enormously useful technique is all branches of astronomy. In principle the simple prism or grating spectroscope works in the same way of spectroscopes attached to professional telescopes.

The video clip in supplementary material (available at stacks.iop.org/physed/45/231/mmedia) shows students in a lecture theatre for the Star Works presentation and in the laboratory using a Wilmshurst machine, black hole funnel, supernova cola experiment, quantum pin-ball machine, plasma ball and rotating chair. At the end of the laboratory session, students are given a 15 min talk in which connections between the experiments and the Star Works presentation are explained. In general all teachers and students enjoy the Space Day and feel that something useful has been learned.

Discussion

Feedback received from students, teachers and parents is that the Space Day is a useful educational experience, and also gives students a feel for university life. The teacher from one of the Space Day schools said that one year two students cited attendance at the Space Day as the reason for their decision to study science at university.

Acknowledgements

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References

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[i] For those who are interested, the direction of Sagittarius A* is close to the tip of the spout of the ‘tea pot’ in the constellation Sagittarius.